MACS Detector System Cryogenic Filter Assembly
Phase A Study

Description

This cryogenic filter assembly is the first component of the MACS detection system, located downstream of the sample drum and prior to the rest of the detector assembly. It contains a stack of three filters for each detection channel, only one of which intercepts the beam at any given time. The filters must be maintained at cryogenic temperatures; thus they will reside inside a vacuum dewar. The baseline plan is to cool the filters with a mechanical refrigerator rather than using liquid cryogen. The vacuum dewar is mounted on a platform which can be raised and lowered between three positions, allowing the desired filter to be positioned in the beam. This report assumes that NIST is furnishing the filter substrates finished to final dimensions.

Requirements

1. 21 filter stacks (63 filters total) radially spaced 8° apart to match the configuration of the detector assembly. Center of radius is at the sample.
2. Each filter shall view a 2 cm diameter by 4 cm tall sample with a horizontal divergence of at least 2° and a vertical divergence of 8°.
3. Three filters for each channel shall be:
    a. 15 cm Thermalox 995 BeO machining stock (Brush Wellman)
    b. 10 cm Be I220H Rev A type I (Brush Wellman)
    c. 5 cm Pyrolytic Graphite grade ZYH (Advanced Ceramics).
4. All filters cooled to a temperature of 77 K or below. Uniformity requirement of 5° C horizontally across a given filter set. No uniformity requirement vertically.
5. Computer-controlled selection of 3 filter positions.
6. Vacuum dewar to be made of neutron-friendly material (e.g. Al 6061-T6). Dewar walls to have as thin a cross-section as possible in the direction of neutron propagation, over the beam footprint defined for each channel (Req# 2 above).
7. Entire volume between filter substrates to be filled with neutron-absorbing material (e.g. borated Al 1100).
8. Must maintain keep-out zones directly in front of dewar inner radius wall and behind dewar outer radius wall.

Assembly Concept

Figure 1 shows how the filters are arranged radially about the sample, with geometry taken from the MACS Requirements Document, Rev. 2.01 (except for the distance from the sample to the filters, which was chosen simply to provide a reasonable starting point for the concept).

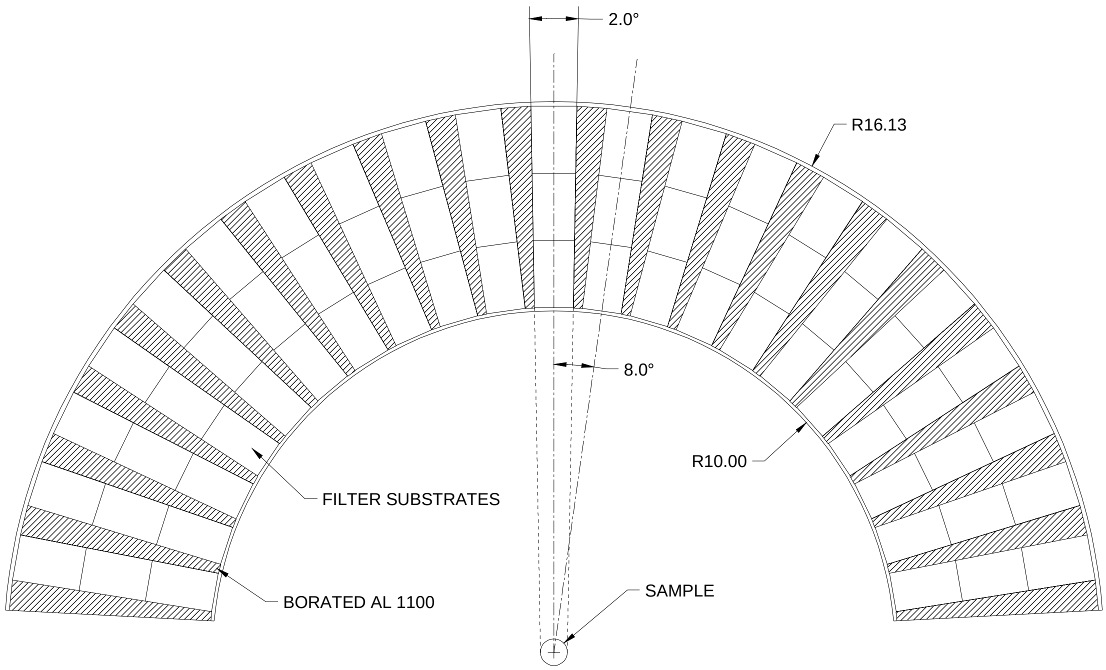

Figure 1. Schematic showing geometry and possible layout of filter substrates. Three different filter thicknesses are indicated for each channel.

The filters are housed in a rigid structure (Figure 2) made entirely of borated aluminum 1100 alloy. The structure provides the mechanical means to mount and position the filters, as well as the thermal path to carry heat from the filters to the cold head. The wedged vertical dividers will be machined from solid plate stock, bolted and pinned to the top and bottom horizontal plates. The horizontal dividers are slotted into the vertical dividers. The structure is mounted inside an aluminum 6061-T6 vacuum dewar (Figures 4 & 5). The dewar body is constructed from rolled and welded plates, with removable top and bottom plates sealed with o-ring gaskets. Where the beam passes through the dewar, thinned rectangular "windows" will be milled into the walls to reduce the amount of aluminum in the beam path.

The filter structure will be mounted to the bottom plate of the dewar with G-10 feet to provide good thermal isolation (Figure 3). They will also act as flexures to allow for the large dimensional change of the aluminum structure when taken to cryogenic temperatures. Across the width of the structure, this change will be on the order of 3 mm, which is significant. With proper design, the G-10 flexures will allow control over the point about which the structure grows and shrinks in the horizontal plane (probably chosen to be the center of the sample).

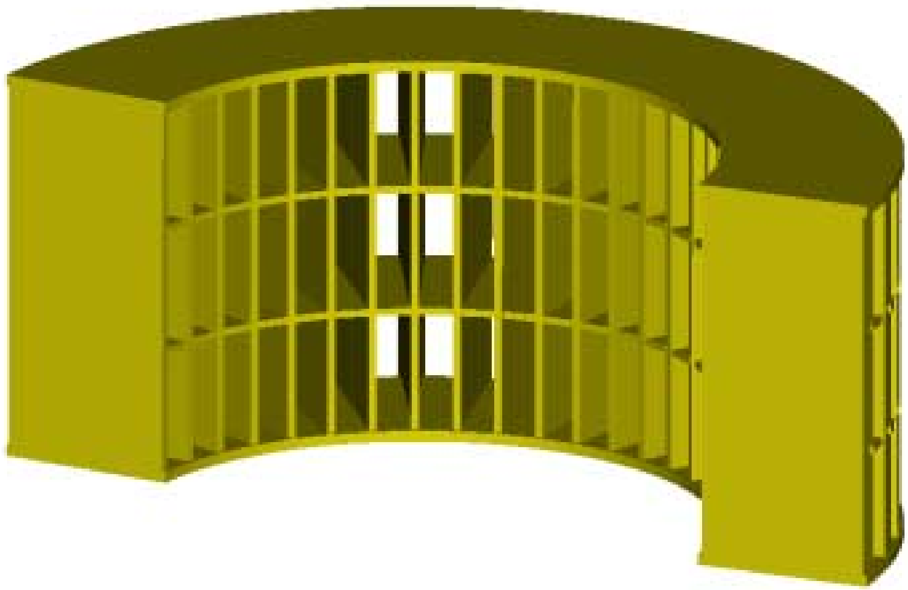

Figure 2. Borated Al 1100 structure concept.

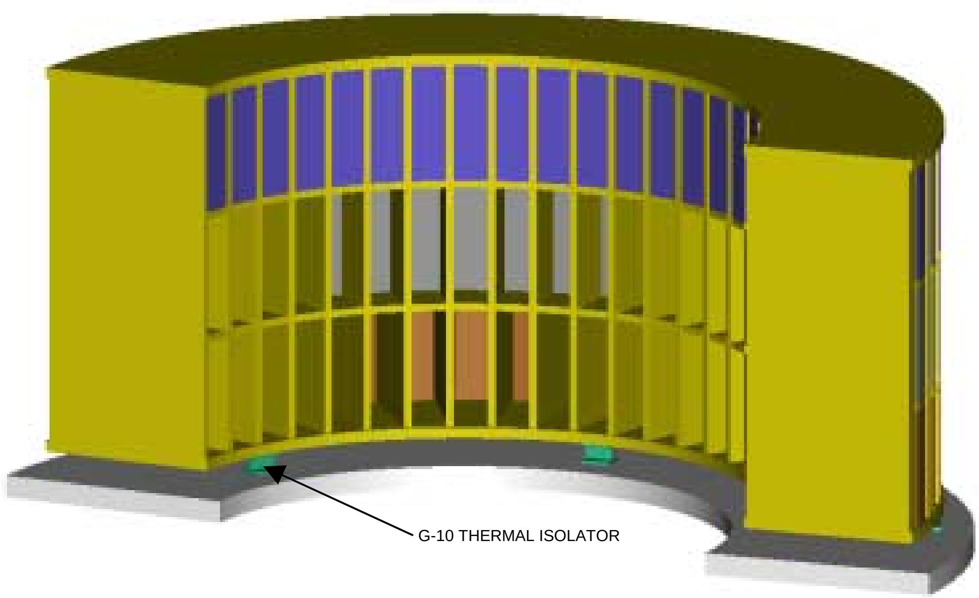

Figure 3. Structure with filters, mounted to dewar baseplate with six G-10 flexure thermal isolators.

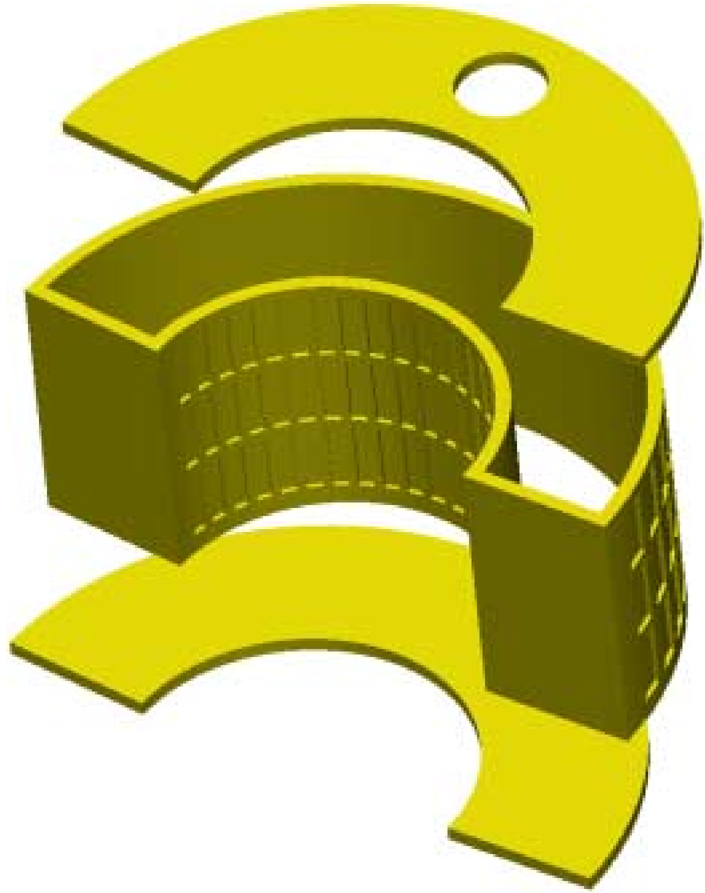

Figure 4. Al 6061-T6 dewar concept, with welded body and removable top and bottom plates (o-ring grooves/gaskets not visible). The hole in the top plate is for the cold head. The thinned rectangular "windows" are visible in the two cylindrical walls.

The filters will be cooled to 77 K or below by means of a closed-cycle cryorefrigerator. These systems generally consist of a cold head mounted to the dewar, a compressor that sits on the floor, and two flexible high-pressure lines joining the two. Although the steady-state heat load at 77 K is calculated to be only a few watts, the large mass of the filters and the structure demands a cooling capacity much greater than that in order to achieve temperature in a reasonable time (days instead of weeks). The system baselined for this study is the Leybold Coolpower 120 T cold head driven by the Coolpak 6200 compressor (Figure 7). It provides 120 W of cooling capacity at 80 K, somewhat less at 77 K or below.

The size of the cold head with respect to the dewar can be seen in the 3D model of the full system in Figure 6. It is mounted to a flanged tube on the top plate of the dewar and extends approximately 17" above the top plate. It is connected to the structure top plate via compliant, highly thermally conducting joints such as the flexible aluminum thermal links from Utah State's Space Dynamics Laboratory.

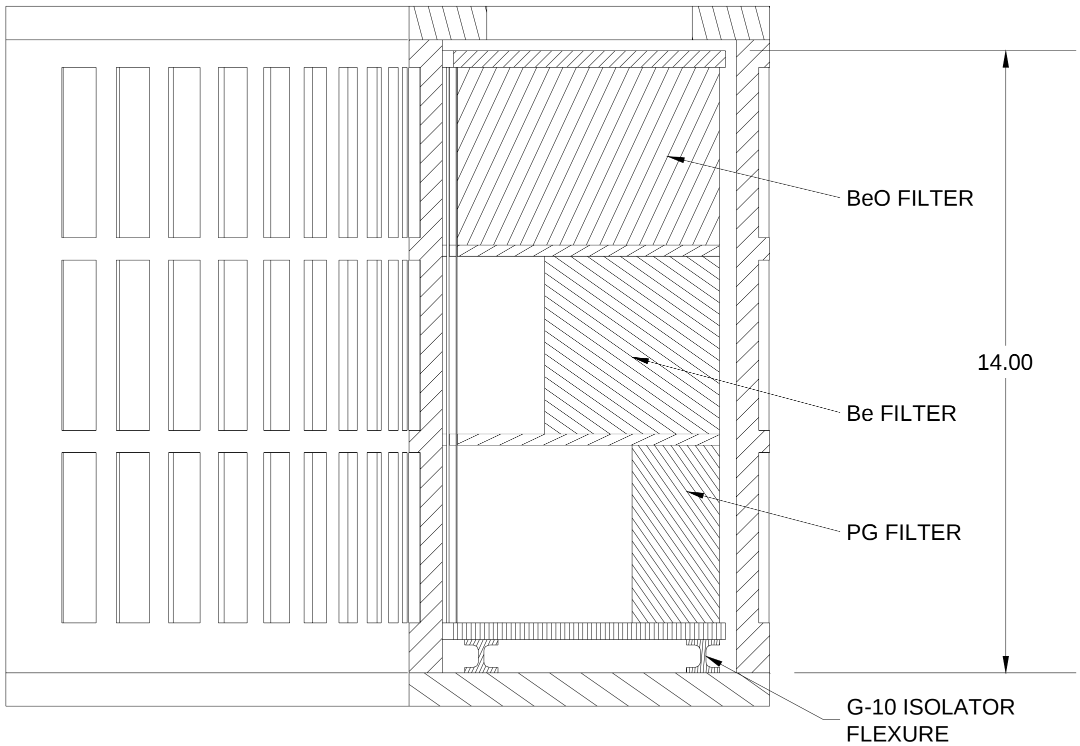

Figure 5. Cross-sectional view of dewar showing filter stack, horizontal structure elements, and G-10 flexure thermal isolators. The dewar wall thickness and size and depth of the thinned "windows" should not be considered meaningful at this point.

The dewar mounts to an elevator platform which is capable of raising and lowering the dewar between the three filter positions, with a total range of travel of about 8 inches (Figure 6). Because only three discrete positions are required, a straightforward actuator for this application is a multiple-position pneumatic cylinder such as the Bimba FOP series (Figure 8). Two or three cylinders with a 2" bore would be sufficient with typical lab air line pressures. Positioning is accomplished via computer-controlled solenoid valves, with flow-control valves to regulate the rate of motion and position sensors to indicate filter selection. Because it is difficult to precisely synchronize the air cylinders, the elevator platform will be designed such that synchronization is not required for straight and level motion.

Finally, a vacuum port and valve will be provided at a convenient location for evacuating the dewar, designed to allow for continuous pumping during operation if necessary. A turbomolecular pump system is included in the cost section.

Design Issues

Due to the brevity of the Phase A study period, several important design issues were identified but not adequately addressed at this time. These include, but are not limited to, the following:

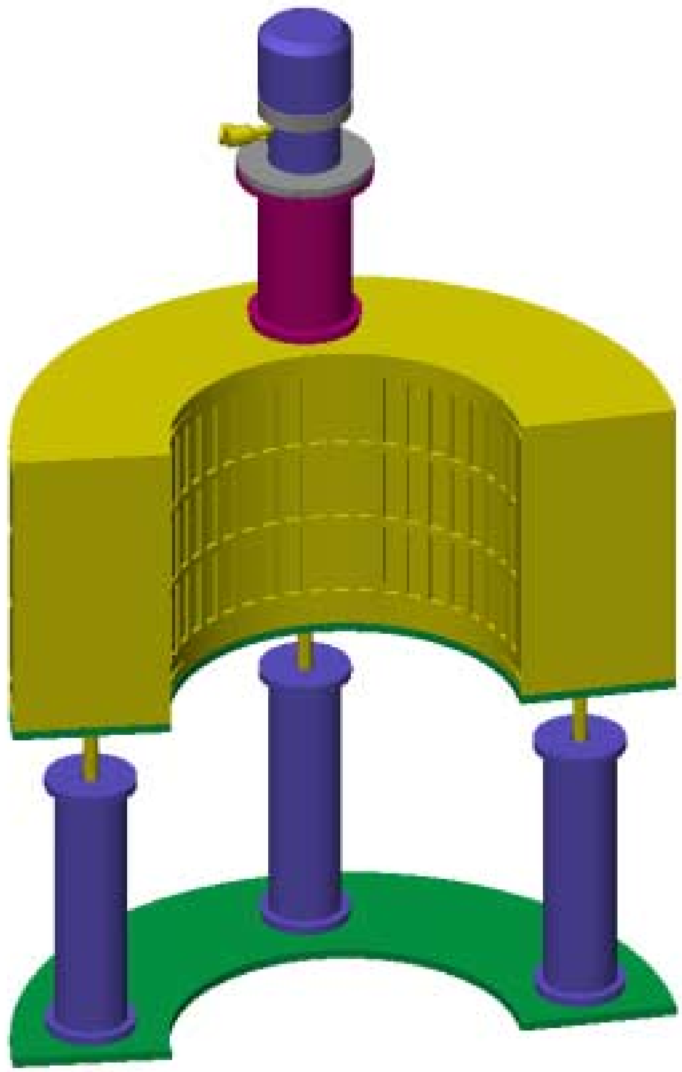

Figure 6. Concept for the full detector system cryogenic filter assembly, not including outboard items (such as the cryocompressor or vacuum pump) or connecting lines and cables.

1. **Filter mounting**
   CTE mismatches between the filter materials and the aluminum structure will need to be considered when mounting the filters. Almost certainly, it will be unacceptable to install the filters at room temperature with no gaps between them and the structure.

2. **Dewar design**
   Finite element analysis will be needed to optimize the dewar wall and "window" thicknesses for this application. Most likely, this analysis will be

performed by the dewar vendor and reviewed by IDG (this assumption is reflected in the cost section).

3. **Cooling capacity**
   The radiative heat load should be approximately 1.5 W if the filters are shrouded entirely in aluminum at 77 K. The heat loss through the G-10 feet should be able to be limited to less than 3 W. However, at room temperature the total heat capacity of the filters and structure is approximately 116,000 $J \cdot K^{-1}$. If 100 W of cooling power can be applied to the filters, it would take ~20 minutes to drop 1 K, or almost 72 hours to get to 77 K if the cooling rate is constant (which will not be true). More extensive thermal analysis will be needed to determine what capacity cryocooler will be adequate for this application, or perhaps, whether a liquid N_2 jump-start system should be employed along with a smaller capacity cryocooler.

Figure 7. Leybold Coolpower 120 T cold head and typical compressor units.

Figure 8. Bimba FOP series three-position air cylinder.

Cost

The following is intended to provide a rough estimate of the cost involved to design, build, test, and integrate the MACS Detector System Cryogenic Filter Assembly. In no way does it constitute a firm or final quote. A large percentage of the cost is tied up in Hardware Procurement, therefore, this task is broken out into further detail below. All other tasks involve IDG personnel costs only, at a rate of $51 per hour. Note that NIST is procuring the filter substrates, finished to final dimensions.

Task	Description	IDG	Contracts
1	Systems Engineering and Project Management	$24,480	$0
2	Filter Substrate Interface Control	$3,825	$0
3	Mechanical Design	$19,125	$0
4	Electrical Design and Assembly	$13,388	$0
5	Software Design and Implementation	$7,650	$0
6	Thermal Analysis	$3,825	$0
7	Fabrication Drawings	$11,475	$0
8	Hardware Procurement	$21,038	$158,065
9	Assemble and Clean	$14,344	$0
10	Test and Qualify	$17,213	$0
11	Support Integration at NIST	$11,475	$0
	Subtotals	$147,836	$158,065
	Total		**$305,901**

8			**Hardware Procurement**			
	Hours	**Weeks**	**Total**	**Cost**	**Labor**	**Contracts**
Dewar	37.5	3	112.5	51	5737.5	70000
Borated Al 1100 stock	37.5	1	37.5	51	1912.5	21000
Cryorefrigerator	37.5	1	37.5	51	1912.5	30250
Vacuum system	18.75	1	18.75	51	956.25	14420
Air cylinders/valves/sensors	37.5	1	37.5	51	1912.5	1750
Thermal monitor/sensors	18.75	1	18.75	51	956.25	2645
Machining	37.5	2	75	51	3825	16000
Miscellaneous hardware	37.5	2	75	51	3825	2000
				Total	$21,038	$158,065